Pilot Study Aerial Radiological Survey Polk and Hillsborough Counties, Florida Final Work Plan

by

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April 2004

Produced for:
The U.S. Environmental Protection Agency, Region IV

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[a]Remote Sensing Laboratory is operated by Bechtel Nevada under contract DE-AC08-96NV11718, for the U.S. Department of Energy.

[b]Argonne National Laboratory is operated by The University of Chicago under contract W-31-109-ENG-38, for the U.S. Department of Energy.

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U.S. Department of Energy

Research sponsored by:
U. S. Environmental Protection Agency, Region IV

Contents

Notation

The following is a list of the acronyms and abbreviations (including units of measure) used in this report. Notation used only in certain equations and tables is defined in the respective equations and tables.

Acronyms and Abbreviations

Ac	actinium
ADC	analog-to-digital converter
AEC	U.S. Atomic Energy Commission
AGL	above ground level
Am	americium
AMS	aerial measurement system
ANL	Argonne National Laboratory
ATSDR	Agency for Toxic Substances and Disease Registry
Bi	bismuth
BN	Bechtel Nevada
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
COPC	constituent of potential concern
Co	cobalt
Cs	cesium
DGPS	differential global positioning system
DOE	U.S. Department of Energy
DQO	data quality objective
EPA	U.S. Environmental Protection Agency
FBO	Fixed Base Operator (airport facility support)
FFA	Federal Facilities Agreement
FUSRAP	Formerly Utilized Sites Remedial Action Program
GC	gross count
GPS	global positioning system
HRS	Hazard Ranking System
HPGe	high-purity germanium
IAG	interagency agreement
K	potassium

MDA	minimum detectable activity
MMGC	man-made gross count
MSL	mean sea level
NaI	sodium iodide
NCRP	National Council on Radiation Protection and Measurements
NIST	National Institute of Standards and Technology
NNSA	National Nuclear Security Administration
NORM	naturally occurring radioactive materials
NPL	National Priorities List
NRC	Nuclear Regulatory Commission
NRHP	*National Register of Historic Places*
NSO	Nevada Site Office
ORNL	Oak Ridge National Laboratory
Pa	protactinium
Pb	lead
PRG	preliminary remediation goal
QA	quality assurance
Ra	radium
RCRA	Resource Conservation and Recovery Act
RDGPS	real-time differential global positioning system
REDAC	Radiation and Environmental Data Analyzer and Computer
REDAR	Radiation and Environmental Data Acquisition and Recorder
Rn	radon
ROD	Record of Decision
RSL	Remote Sensing Laboratory
SOP	standing operating procedure
TAB	typical area background
TENORM	technologically enhanced naturally occurring radioactive materials
Th	thorium
Tl	thallium
U	uranium

Units of Measure

bbl	barrel(s)	m^2	square meter(s)
Bq	becquerel(s)	m^3	cubic meter(s)
Ci	curie(s)	mCi	millicurie(s)
µCi	microcurie(s)	mg	milligram(s)
cpm	count(s) per minute	mi	mile(s)
cps	count(s) per second	mi^2	square mile(s)
d	day(s)	min	minute(s)
ft	foot (feet)	mL	milliliter(s)
ft^2	square foot (feet)	mm	millimeter(s)
ft^3	cubic foot (feet)	mph	mile(s) per hour
gal	gallon(s)	pCi	picocurie(s)
g	gram(s)	ppm	parts per million
Gy	gray(s)	R	roentgen(s)
h	hour(s)	µR	microroentgen(s)
in.	inch(es)	rad	radiation absorbed dose
keV	kiloelectron volt(s)	s	second(s)
kg	kilogram(s)	yd^3	cubic yard(s)
lb	pound(s)	yr	year(s)
m	meter(s)		

Abstract

The U.S. Environmental Protection Agency (EPA) is initiating an investigation to assess the potential for human exposures to excess levels of gamma radiation and radon gas for individuals residing in dwellings constructed over formerly mined phosphate lands in central Florida.

This investigation involves a pilot study aerial radiological survey to characterize gamma-emitting radioactive materials, both natural and anthropogenic. The survey will be performed using sodium iodide gamma radiation detectors mounted on a Bell 412 helicopter flown over the former phosphate mining areas. Using an aerial platform for the survey will allow large areas to be quickly assessed regarding the magnitude, nature, and extent of gamma-emitting radioisotopes. The main objectives of this survey are to identify and map areas that exhibit excess or elevated levels of radiation and to gather site-specific data that can be used to evaluate the potential risk to human health.

The Bell 412 twin-engine helicopter will fly a set of preplanned flight paths over the four pilot study areas to be investigated at an altitude of 46 m (150 feet), which is the lowest practical altitude for helicopter flights over populated areas. If conditions or topography make this an unsafe altitude, the survey may be conducted from a higher altitude.

Before every data-gathering flight, the helicopter will take readings over a designated land and water test/calibration strip to aid in data analysis and as a data quality assurance procedure. In addition, flights and readings will be made to determine the cosmic and atmospheric contributions to the radiation background during the survey period. These data will be used to determine the terrestrial contribution to the exposure measured by the sensors.

The data will be analyzed, and the extent of excess or elevated levels of anthropogenic gamma-emitting radioisotopes will be determined, as will the nature and extent of the natural gamma-emitting radioisotopes present. A detailed discussion of the sensitivity and resolution of the detector system will be provided in the project report. The results of this survey will be given to the U.S. EPA in the form of a written report and processed electronic geographic information system data.

Section 1
Introduction and Purpose

1.1 Background

A pilot study aerial radiological survey of portions of Polk and Hillsborough Counties in central Florida (Figure 1) will be conducted to assess, within the limits of the detector system, the nature and extent of the gamma-emitting radioisotopes from both technologically enhanced naturally occurring radioactive materials (TENORM) and natural background sources. The purpose of the survey is to assess the potential for human exposures to elevated levels of gamma radiation and radon gas for individuals residing in dwellings constructed over formerly mined phosphate lands. The results from this aerial survey will be used to determine if additional actions (e.g., more detailed ground-based measurements, remedial actions, etc.) are warranted for portions of the survey areas.

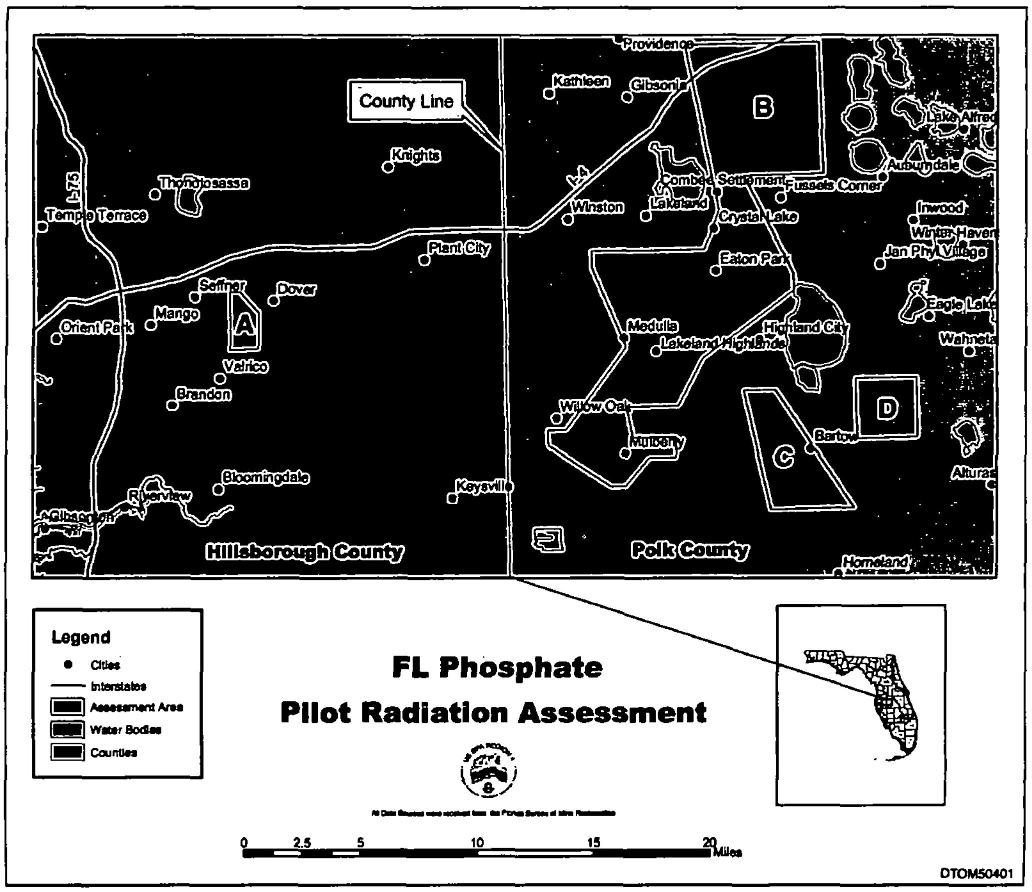

Figure 1 Pilot Study Areas to be Surveyed by the AMS Helicopter

This aerial radiological survey has been initiated as part of the response to concerns associated with recent information regarding residential use of former phosphate-mined land. A report published in November, 1998, by the U.S. General Accounting Office (GAO), titled, *Hazardous Waste: Unaddressed Risks at Many Potential Superfund Sites*, identified 21 phosphate mining-related sites in Florida that had not yet been addressed through the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process. While reviewing these sites, the U.S. Environmental Protection Agency (EPA) discovered that in addition to the phosphate mining sites that need to be addressed, several residential areas have been developed on former phosphate mine property. The potential exists for residents with dwellings overlying former mines to be exposed to elevated levels of radioactive isotopes.

Phosphate ores contain naturally occurring radioactive isotopes at low concentrations, including uranium, thorium, and radium. The primary constituent of potential concern (COPC) for this survey is radium-226 (Ra-226). While this radionuclide occurs naturally in soil, the processes used for phosphate extraction and production tend to redistribute and concentrate Ra-226 in the clay slurry and sand tailings that are left after removal of the phosphate. Radium-226 is of concern because at elevated soil concentrations it can cause exposure to gamma radiation and radon (Rn-222) gas.

The Remote Sensing Laboratory (RSL), operated by Bechtel Nevada (BN) for the U.S. Department of Energy (DOE), National Nuclear Security Administration, Nevada Site Office (DOE/NSO) will conduct the aerial radiological survey with support from Argonne National Laboratory (ANL). Specialized airborne sensors will be used to characterize the terrestrial radiological conditions over the four pilot study areas. Maps showing the extent and degree of elevated levels of radioactivity due to phosphate mining operations in the study areas will be developed from this characterization data. The RSL will determine background radiation levels and any elevated levels of radiation detected over the study areas using the aerial measurement system (AMS) in a DOE helicopter. ANL will provide required technical support related to impact analysis and quality assurance (QA).

The RSL and ANL have proven capabilities for detecting radioactive materials by utilizing both aerial and ground-based survey platforms and for analyzing these data within a restoration environment. Recent surveys at the U.S. Army's Aberdeen Proving Ground and the U.S. Navy's China Lake Naval Air Weapons Station have been successful in defining the relative amounts and spatial extent of surface radioactivity and in contributing to an understanding of the impacts of this contamination.

This pilot study aerial radiological survey is designed to identify areas that may have been impacted by phosphate mining activities and to determine if any areas exist that warrant further investigation, to determine if additional actions are necessary to protect individuals from exposure to radioactive materials. A secondary objective of the survey is to produce data that can be used in conjunction with other site information, to guide potential future restoration efforts.

1.2 Scope of Work for the Aerial Radiological Survey

The aerial radiological survey will be composed of three technical components and a project management/QA component (all of which are described in more detail below). The three technical components of this project are to:

- Conduct an aerial radiological survey of the four pilot study areas;

- Take corroborative ground-based measurements at selected locations to demonstrate the ability of the aerial survey to reproduce ground-based measurement results; and

- Determine the detectability limits for the radiological COPCs, which are necessary to establish ceiling values for the amount of each that could be present yet go undetected. Since Ra-226 and its daughter product bismuth-214 (Bi-214) are assumed to be in secular equilibrium, the minimum quantity of Ra-226 detectable by the aerial survey will be the same as that calculated for Bi-214.

1.2.1 Aerial Survey

The aerial radiological survey of the four pilot survey areas will cover a total area of 69,626 acres (108.8 square miles [mi^2]); see Figure 1 and Table 1. The survey will acquire georeferenced, time-resolved gamma spectra from a low-flying helicopter. Aerial measurements will be taken at a ground speed of 80 knots (92 miles per hour [mph]) at 46 m (150 ft) above ground level (AGL) with a nominal spacing of 76 m (250 ft) between flight paths, safety permitting.

Table 1 Pilot Study Areas

Area Designator	Square Miles	Acres	Latitude[a] (deg-min-sec)	Longitude[a] (deg-min-sec)
A	2.70	1,728	N27° 58′ 33.9″	W82° 14′ 29.4″
B	86.53	55,382	N28° 0′ 10.6″	W81° 55′ 6.1″
C	12.74	8,154	N27° 58′ 33.9″	W81° 51′ 34.3″
D	6.82	4,362	N27° 55′ 12.6″	W81° 47′ 18.2″

[a] Coordinates cited are located near the center of each pilot study area.

Data will be processed to map the total exposure rate, man-made exposure rate (apparent), and Ra-226 concentration (derived from excess Bi-214).

Results for Ra-226 will be reported in terms of equivalent surface concentration and uniform soil concentration for distributed sources.

1.2.2 Corroborative Ground-Based Measurements

Corroborative measurements will be made at a minimum of six selected locations (typically at a point of minimal spatial radiological gradient), and then the measurement results will be compared with the aerial results. The measurements at each location will consist of a field gamma spectroscopy measurement, done with a high-purity germanium (HPGe) detector, and a pressurized ionization chamber measurement. These measurements and their comparison with the aerial data will be presented in the report. On the basis of the comparison of the ground and aerial measurements, the report will also estimate the site-wide average concentrations of Ra-226.

1.2.3 Project Management

Project management will consist of those activities necessary to control and support the principal tasks cited above.

1.2.3.1 Project Planning Support

Project planning support will consist of the development of this work plan, which describes the purpose of the aerial radiological survey and the data quality objectives (DQOs) to support the initial site investigation decisions. The work plan also provides a general description of each of the aerial survey data acquisition and data analysis tasks and specifies project QA requirements. Deliverables under this task include a preliminary draft work plan for internal review, a final draft for regulatory review, and a final work plan. Other activities included under this task include attending meetings and/or conference calls with regulators and stakeholders to resolve questions on the draft plan, as well as participation in coordination and planning meetings, conference calls, and site visits, as determined to be necessary by the EPA Project Manager.

1.2.3.2 Quality Assurance and Data Evaluation Technical Support

This support will involve an independent technical assessment of the data acquisition and analysis techniques used by the RSL, evaluation of uncertainties associated with these techniques, and interpretation of final survey results, including an assessment of the natural background and anthropogenic radioisotope spatial information developed by the RSL to identify anomalies that should be highlighted for further investigation.

This support will also involve integration of pilot study data into existing EPA databases and development of a feasibility study for Internet-based information management for this project.

1.2.3.3 Report Preparation

Report preparation includes the generation of a report that contains site history and background, survey methods, results, and data analysis; production of maps and other graphics products; technical review and editing; and production of the final survey report. It is anticipated that the introductory sections of the report will be developed in coordination with EPA Region IV personnel, including descriptions of the survey purpose and objectives, site background, physical characteristics and land use, and results of the QA and data analysis process. The report format and outline will be developed in coordination with the EPA Project Manager.

This task will also include preparation of an interim draft report, final draft report, and final report, with associated review and comment-resolution cycles. Up to 25 copies of the final report will be published. The EPA Project Manager will receive a CD containing a copy of the report in electronic format. This task also includes production of graphics products for public and regulatory meetings and attendance at meetings, as requested by the EPA Project Manager.

1.3 Site Description

1.3.1 Pilot Study Area Locations

State and Federal agencies have documented areas totaling approximately 7,140 acres covering portions of Polk and Hillsborough Counties, Florida, where land formerly mined for phosphate has been developed for residential use. The primary focus of the pilot study aerial radiological survey will be on these residential areas. Figure 1 shows the four specific regions in Polk and Hillsborough Counties that have been selected by the EPA for the initial aerial radiological survey, and Table 1 provides the approximate area for each region. The survey area includes residential developments on former phosphate mining land, as well as the Tenoroc phosphate mine site northeast of Lakeland, Florida. The total area for aerial survey coverage within the four designated regions is approximately 69,626 acres (108.8 mi^2).

1.3.2 Climate

An aerial radiological survey will be performed for this project over portions of Polk and Hillsborough Counties. Polk and Hillsborough Counties are located in central Florida, about midway between the east and west coasts and midway between the Georgia-Florida border and the southern tip of the state. Polk County is located about 25 miles east of Tampa and about 35 miles southwest of Orlando, on the I-4 corridor. Hillsborough County is located 82 miles southwest of Orlando and 268 miles northwest of Miami.

Central Florida's subtropical weather is dominated by the water that surrounds it. The Atlantic Ocean in the east and the Gulf of Mexico in the west provide a stabilizing force that maintains a mild climate. Polk County receives about 50 in. of rainfall annually; Hillsborough County receives somewhat less annual precipitation, 46.7 in. August is the wettest month of the year in central Florida, with an average precipitation of about 7.6 in. The average annual temperature for central Florida is approximately 73°F. The average coolest monthly temperature occurs in January, about 60°F; the warmest monthly average occurs in August, 82°F. The average humidity is 74%, and there are about 259 days per year without precipitation.

1.3.3 Geography and Topography

Polk County occupies 1,286,000 acres (2,010 mi^2), with a land area of 1,200,000 acres (1,875 mi^2) (Figure 2).

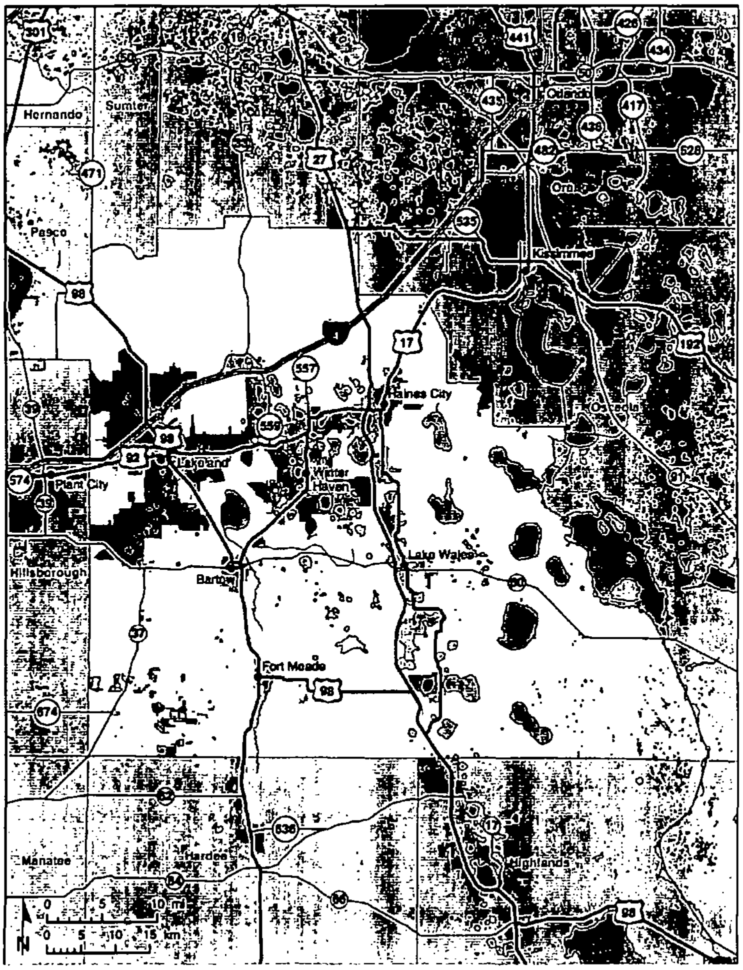

Figure 2 Polk County, Florida

Polk County is larger than the state of Rhode Island, and it is the fourth largest county in the state. Polk County is a hilly, lake-dotted region with swampy regions in the north. The elevation of Polk County ranges from 0 to about 325 ft (at Iron Mountain) above mean sea level (MSL). High grounds in Polk County mostly occur in the Lake Wales Ridge area in eastern Polk County. This area was once a chain of islands.

Hillsborough County occupies a total land and water area of 686,000 acres (1,072 mi^2) (Figure 3).

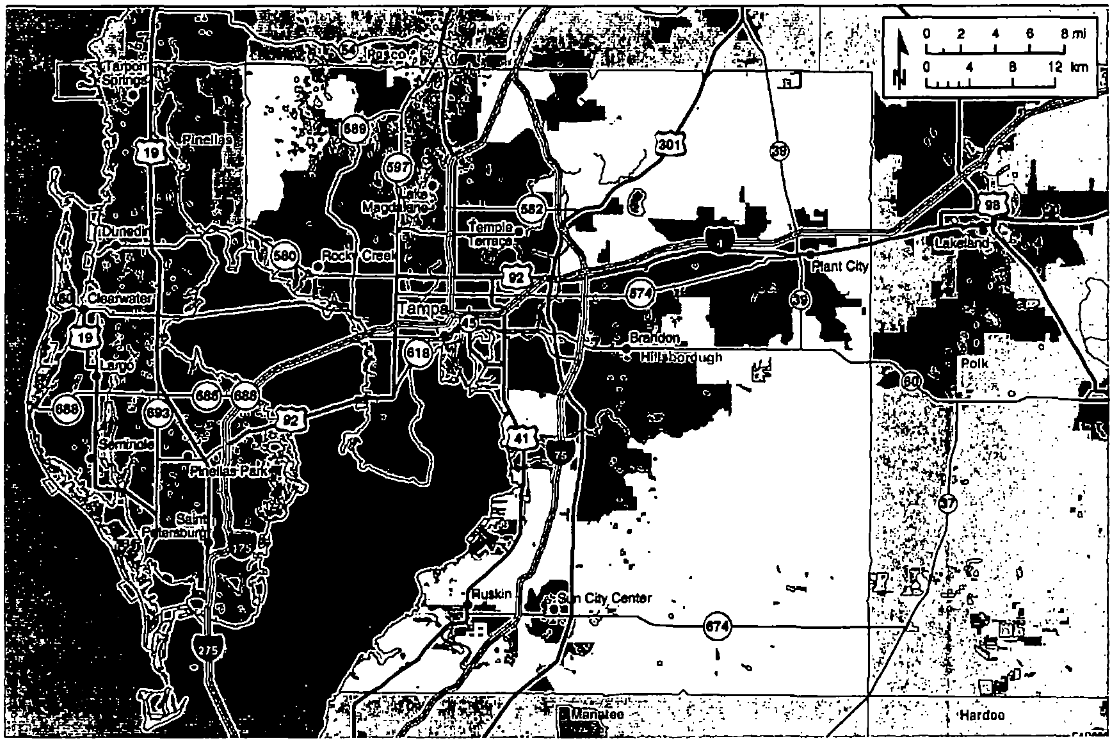

Figure 3 Hillsborough County, Florida

The county has 15,360 acres (24 mi^2) of surface water and a rolling and level terrain with many small lakes. It has an elevation that ranges from about 0 to 170 ft MSL.

1.3.4 Geology and Soils

The Florida peninsula is composed of carbonate rock (limestone and dolomite). This rock was deposited when Florida was mostly below sea level. Surface and near-surface sediments in central Florida consist of quartz, sand, clay, phosphorite, limestone, and dolomite. These sediments range in age from Late Eocene to Holocene (40 million years ago to present). Phosphate rock in central Florida is usually found at a depth of about 15 to 50 ft beneath the ground surface in a mixture of phosphate pebbles, sand, and clay known as phosphate matrix. Unconsolidated material above this layer is referred to as the overburden.

Overburden soils in the vicinity of central Florida include Apopka, Candler, Eaton, Pomona, Lynne, Malabar, Neilhurst, Ona, St. Lucie, Hontoon, Arents, Pomello, and Urban Land. Leachability and soil runoff vary from low to high, depending on the specific soil type.

1.3.5 Hydrology

Polk County has 554 natural freshwater lakes and hundreds of square miles of wetlands. A major portion of northern Polk County (approximately 220,000 acres) is known as the "Green Swamp." Polk County constitutes a portion of the headwaters for six central Florida Rivers (Peace, Kissimmee, Alafia, Hillsborough, Oklawaha, and Withlacoochee). Approximately 35% of surface water runoff from Polk County drains to the Peace River, 35% to the Kissimmee River, 8% to the Alafia River, 4% to the Hillsborough River, 3% to the Oklawaha River, and 15% to the Withlacoochee River.

Hillsborough County has 24 mi^2 of inland water, including 150 freshwater lakes. Rivers in the county include: Hillsborough, Alafia, Little Alafia, Little Manatee, Palm, and the New River. The county also has 2,671 acres of conservation areas and wetlands.

Three principal aquifers occur in the central Florida area: the Floridan (deepest), the Intermediate Aquifer, and the Surficial Aquifer (shallowest). The Floridan Aquifer underlies 82,000 mi^2 of Florida and parts of Alabama, Georgia, and South Carolina. This aquifer is recharged locally. The Floridan Aquifer is the principal source of water for municipal, agricultural, and industrial use. The potentiometric high of the aquifer lies in northern Polk County, near Polk City. Water flows outward from this high in all directions.

Water use in Polk County in 2000 was about 343 million gallons per day. Of this water, 41% was used by agriculture, 28% by industry and mining, 26% by public water supplies, and 5% by recreation. Most water in the Hillsborough County area comes from wells drilled into the Floridan Aquifer (greater than 80% of the water use). These wells are fed by rainwater. Water management is under the jurisdiction of the Southwest Florida Water Management District. Existing water use for the Southwest Florida Water Management District is about 121 million gallons per day from eleven well fields.

1.3.6 Demography and Land Use

The population of Polk County in 2000 was 483,924, with 187,233 individual households and 132,373 families residing in the county. Between 1960 and 2000, the population of Polk County increased from about 195,000 to 484,000 people. In 2001, the population grew to 496,112. Most of the population increase has been concentrated in or around cities and towns located along the ridges in the interior of the county. The largest towns in the County are Lakeland, Winter Haven, and Bartow.

The population of Hillsborough County in 2000 was larger than that of Polk County, which was 998,948, with 391,357 households and 255,164 families residing in the county. In 2001, the population grew to 1,026,906. The largest towns in the county are Tampa, Plant City, and Temple Terrace.

The predominant agricultural land use in Polk County is citrus cultivation, and the county ranks first statewide in terms of total annual citrus production. In 1997, about 622,000 acres were dedicated to agriculture. This land represents about 52% of the land available in the county. About two-thirds of the agricultural lands were dedicated to pastures of all types; about 20% was dedicated to citrus. The principal industry in the county is the mining of pebble-phosphate, a key ingredient in fertilizer production. Approximately 1,500 acres are zoned industrial.

In 1997, Hillsborough County had 247,502 acres of land in farms (about 37% of the land available), 150,983 acres of land in pastures of all kinds (about 23% of the land available), and 31,754 acres in orchards (about 5% of the land available). Of the farms, most were used to raise fruits, nuts, and berries. Approximately 25,579 acres are zoned industrial.

1.3.7 Phosphate and Phosphate Mining

Phosphate is an essential nutrient for plant and animal growth. Mining of phosphate ores began in Florida in about 1889. The primary source of phosphate rock is located in west-central Florida from a phosphate deposit known as the Bone Valley Formation (so named because of the large number of fossils found in the deposit). This formation covers about 3,000 square miles.

Mining phosphate is a major activity in both Polk and Hillsborough Counties. As discussed above, phosphate ore is found at a depth that ranges from 15 to 50 feet in deposits that consist of equal parts sand, clay, and phosphate rock. The current method for extracting phosphate rock involves strip mining, in which draglines or very large cranes remove the top layer of soil and scoop up the phosphate matrix. The matrix is placed in a pit where high-pressure water guns create a slurry that can be pumped to a processing plant.

At the processing plant, the sand and clay are separated from the phosphate rock by a beneficiation process. After the largest particles have been removed, the slurry is run through a hydrocyclone that uses centrifugal force to remove the clay. Waste clay is pumped to a settling pond. Sand and sand-sized particles are subjected to a process that uses chemical reagents, water, and physical force to separate the sand and phosphate. The tailings, or waste products, of this process are used in dam construction and land reclamation. The phosphate rock is then trucked to a chemical processing plant.

At the chemical processing plant, the phosphate rock is mixed with sulfuric acid, creating phosphoric acid that is used in fertilizer. When the sulfuric acid reacts with phosphate, it produces a slightly radioactive byproduct, phosphogypsum. About 30 million tons of phosphogypsum are produced annually, and there is a billion tons of the material stacked across the state.

The waste products of phosphate mining are slightly radioactive, because some geological strata, such as marine phosphorite, contain elevated concentrations of uranium, thorium, and their decay products. The phosphate deposits of central Florida contain uranium concentrations and its decay products at levels 30 to 60 times greater than those found in average soil and rock. Uranium concentrations in the phosphate matrix have an average concentration of 100 to 150 parts per million (ppm). The primary source of radioactivity in the clay slurry, sand tailings, and gypsum is Ra-226.

After the phosphate ore is removed from a mine, the mine is closed and the land is reclaimed, including the clay-settling and sand-tailing areas and the mine area itself. In a six county region of EPA Region 4, low-level radiation may pose a threat to residences constructed on top of reclaimed phosphate mining lands. State estimates indicate that about 150,000 acres of land have been mined and have been or could be used for some type of development. Census data indicates that as much as 7,140 acres may be currently used for residential purposes. There are an additional 400,000 acres of land in various stages of mining that, when completed, have the potential for future development.

Section 2
Data Collection Methods for the Pilot Study Aerial Radiological Survey

2.1 Collection Area

Aerial measurement techniques will be used to evaluate the distribution of gamma-emitting radioisotopes within the four selected pilot study areas. Figure 1 and Table 1 (presented in Section 1) show the general location and size of each area to be surveyed.

Data will be collected by the AMS mounted on a Bell 412 twin-engine helicopter. The helicopter will fly in preplanned flight paths over the survey areas at an altitude of 46 m (150 ft) above ground level (AGL), the lowest practical altitude for helicopter flights over populated areas. If conditions or topography make this an unsafe altitude, the survey may be conducted from a higher altitude. Flight paths are designed to provide complete coverage of the areas to be surveyed.

Before every data-gathering flight, the helicopter will take readings over a designated land and water test/calibration strip to aid in data analysis and as a data quality assurance procedure. In addition, measurements will be made to determine the cosmic and atmospheric contributions to the radiation background during the survey period.

No physical material samples will be taken during this survey.

2.2 Collection System History

The AMS that will be used for this survey has been used to conduct hundreds of aerial radiological surveys throughout the world. It was initially developed in 1958 and has been continually updated. Surveys have been performed over most DOE and commercial nuclear reactor sites, as well as at many environmental cleanup sites in the United States.

The AMS equipment (Figure 4) consists of a radiation detector and data acquisition computer system mounted on a high-performance helicopter. A field-portable data-analysis computer system supported the helicopter survey operations and allowed the spectral data to be presented as isopleth contour maps of exposure rates and isotopic intensities.

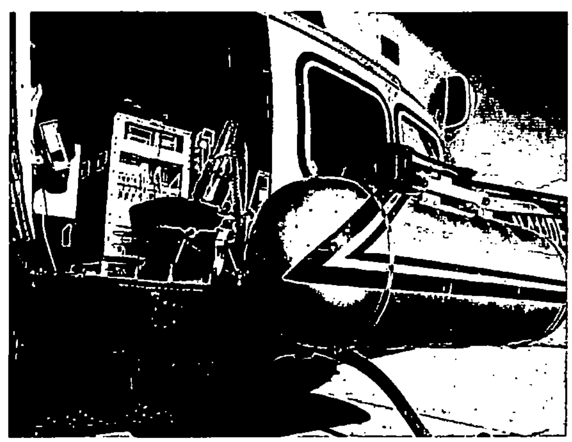

Figure 4 Photo Showing a Pod Containing the Sodium Iodide (NaI) Detectors beneath a Twin-Engine Bell 412 Helicopter

2.3 Instruments

The survey will be conducted with an array of twelve 2- x 4- x 16-in. thallium-activated sodium-iodide (NaI[Tl]) detectors mounted on a twin-engine Bell 412 helicopter, as shown in Figure 4. The AMS data acquisition system — Radiation and Environmental Data Acquisition and Recorder, Model V (REDAR V) — collects second-by-second spectral information, spanning 0 to 4,000 keV (kiloelectron volts), as illustrated in Figure 5. Gamma emissions from any isotopes that are of concern for this study fall within this energy range. The measured energy spectrum permits the data analyst to distinguish between excess or elevated levels of radioactivity and simple changes in the natural background radiation. The spectral information also helps identify specific radioactive isotopes.

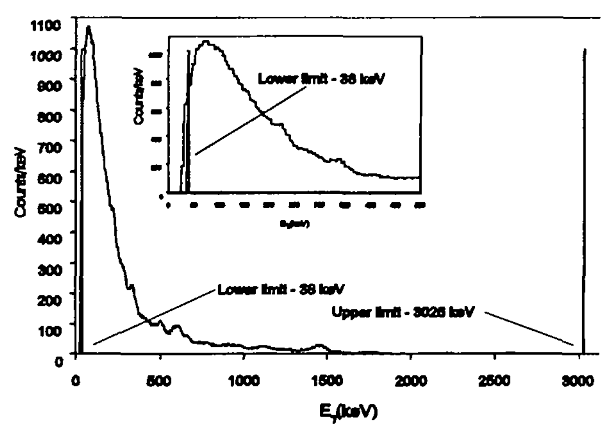

Figure 5 System Sensitivity to Gamma Ray Energy (The figure shows an example spectrum of energy values. Also, the lower and upper energy limits cited refer to mathematical algorithms discussed in Section 2.6.)

To provide extra capability to the collection system, the signals from the 12 NaI detectors are routed to four analog-to-digital converters (ADCs). The signals from all 12 detectors are fed into one ADC to produce the maximum sensitivity, and the signals from a single detector are fed into a separate ADC to ensure useful data if detected activities become too high. Finally, the signals from the remaining detectors in each pod are fed into the two remaining ADCs to provide redundancy in the data collection effort and to provide a quality assurance function.

Table 2 shows examples of the strength of both a point source and a distributed surface activity source that can be detected by the AMS. In the table, the isotopes Ra-226 and Bi-214 are used as examples. In an actual survey, the full spectrum of detected gamma radiation compiled by the AMS allows the identification of any gamma-emitting radioisotopes present (in detectable amounts) rather than just target radioisotopes. Each radioisotope decays with a characteristic set of gamma-ray emissions. Each of these gamma emissions has a specific energy. The analyst can identify a decaying radioisotope by examining the energy spectrum from 38

Table 2 Sensitivity of the Measurements at Various Altitudes for both Ra-226 and Bi-214

Altitude (ft AGL)	^{226}Ra (186 keV)	^{214}Bi (1,764 keV)
Point source sensitivity (mCi)		
50	0.6	0.1
150	8.2	1.7
300	59.0	8.1
Distributed surface source ($\mu Ci/m^2$)		
50	0.89	0.26
150	1.65	0.33
300	3.77	0.45

to 3,026 keV and comparing the various energies of the detected gamma emissions. This technique allows a more accurate determination of the amounts of anthropogenic radioisotopes present compared with background levels, even if background levels change spatially over the survey area. As shown in Table 2, this approach has different sensitivities to different radioisotopes because of the number and energy of gamma emissions that characterize each isotope. Appendix A contains a brief primer on radiation, exposure, and dose.

Helicopter flight positions during the surveys will be continuously determined with a radar altimeter and a real-time differential global positioning system (RDGPS). The RDGPS provides latitude and longitude position with an accuracy of better than ±5 m (16 ft). With this RDGPS, GPS data from a network of precisely measured locations surrounding the United States are transmitted to a control center, where range, timing, and ephemeris errors from the 24 GPS satellites are evaluated. Corrections for each satellite are then up-linked to a geostationary satellite, broadcast back to earth, and utilized by the helicopter RDGPS. Without these corrections, GPS accuracy would have been ±20 to 30 m (66 to 98 ft). The radar altimeter determined the aircraft's altitude by measuring the round-trip propagation time of a signal reflected off the ground. For altitudes up to 300 m (~1,000 ft), the accuracy of this system is ±0.6 m (2 ft), or ±2%, whichever is greater.

In aerial surveys, an aircraft's altitude, flight line spacing, and speed are chosen to optimize the detector's sensitivity to radioisotopes and spatial resolution while maintaining a safe and efficient flight configuration. For this survey, the position information will be directed to an aircraft steering indicator and used to guide the aircraft along predetermined, parallel flight lines. The position information from the RDGPS and the radar altimeter data will be simultaneously recorded, along with the spectral information from the NaI(Tl) detectors, at one-second intervals for post-flight analysis.

A field-portable computer-based system, the Radiation and Environmental Data Analyzer and Computer (REDAC) system, will be used to evaluate the acquired data immediately following each survey flight. The REDAC system consists primarily of a portable computer, software, and a large-bed plotter.

2.4 Collection Methods

2.4.1 Aerial Collection

Data will be collected by using a Bell 412 helicopter and the AMS equipment described above. The helicopter will be flown at a constant speed of 80 knots (41 m [135 ft] per second) and at an altitude of 46 m (150 ft) AGL over the survey area in a series of parallel flight lines (Figure 6). This procedure will be continued until all of the desired area is surveyed.

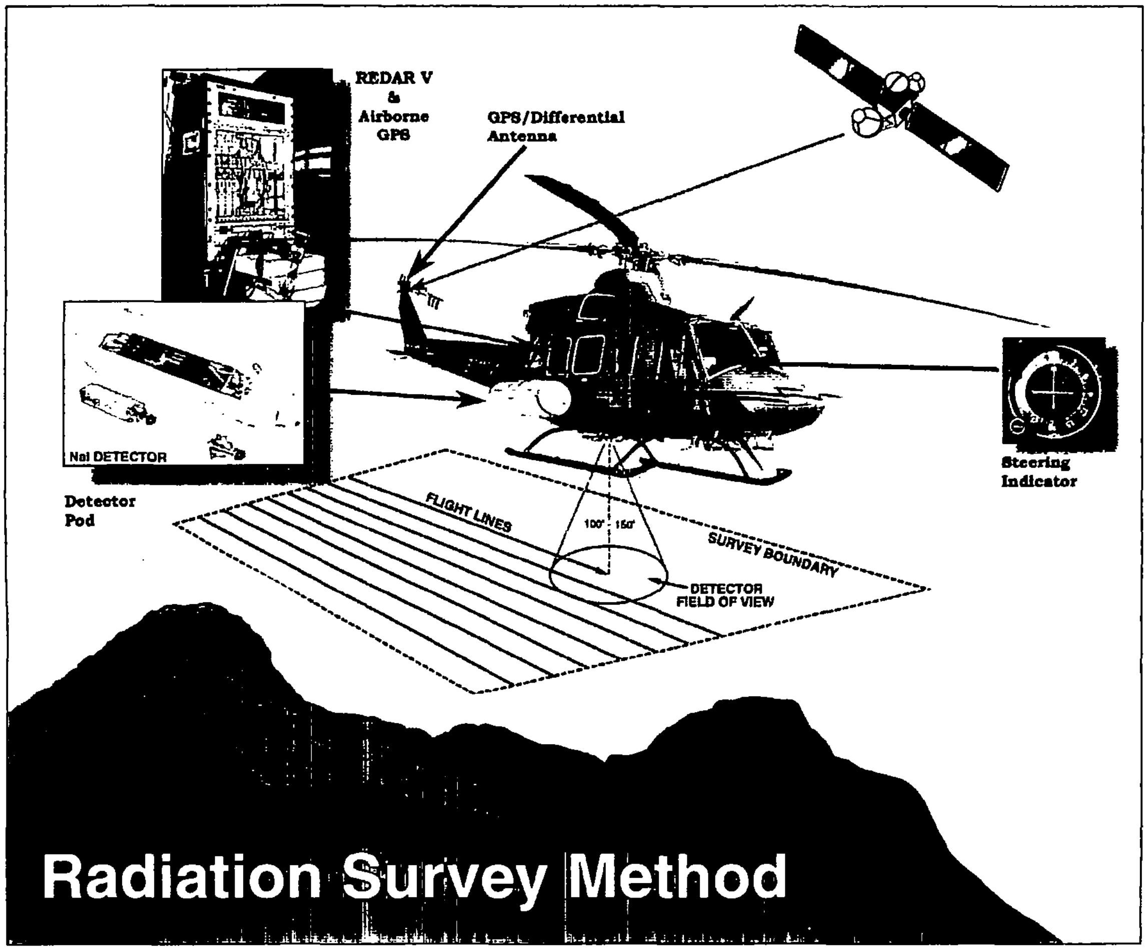

Figure 6 Overview of the Data Collection Activities (Image courtesy of DOE's RSL)

The data set for this survey, collected at the rate of one measurement per second during the flight, will consist of positional and altitude data, atmospheric information, and gamma-ray energy spectra. The first flight of the survey will be a reconnaissance flight conducted above 152 m (500 ft) AGL to verify and update the existing flight hazard maps. The hazard maps will be updated with the locations of towers, power lines, and other high structures that could present a hazard to a helicopter flying at 46 m (150 ft) AGL.

The survey will consist of parallel flight lines spaced nominally at 76 m (250 ft) to provide complete coverage. Each data collection flight will include a pass over the predetermined land/water test lines, passes over the lines in the survey area designated for that flight, and then a repeat of the land/water test lines before landing and preparing for the next flight. These procedures are described in detail below.

Flights over the land/water test lines will be used to calibrate the detectors and to determine the contribution of cosmic and atmospheric radiation to the measurements. The land/water test lines location will be determined at the time of the survey.

2.4.2 Calibration and Data Quality

Fluctuations in atmospheric radon and cosmic radiation will be measured during each flight. These data will be analyzed to determine the contributions to the survey from atmospheric and cosmic sources. In the subsequent calculations, the count rate from radon, equipment, and cosmic radiation will be removed from the aerial data, and appropriate algorithms will be applied.

As described above, a predetermined land and water test line will be established for the pilot study survey. The land and water test lines will be flown and measured as part of each data-gathering flight. Measurements from the land and water test lines will be used to calibrate the instruments, quantify cosmic and atmospheric radon variability, and account for other varying conditions.

An altitude profile (also referred to as an altitude spiral) will be flown in the first days of the survey period. The altitude profile will consist of several traversals of a specific path (usually the land and water test lines) conducted at five or six different altitudes. The air attenuation coefficient and an initial background count rate will be determined from these data. These values will be used to adjust the measurements for minor fluctuations in altitude during subsequent flights.

2.4.3 Ground-Truth Measurements

Six corroborative measurements will be made at selected locations (typically, these locations will have a minimal spatial radiological gradient) and then compared with the aerial results. The measurements at each location will consist of a field gamma spectroscopy measurement with an HPGe detector and one pressurized ionization chamber measurement. These measurements and their comparison with the aerial data will be presented in the report. On the basis of the comparison of the ground and aerial measurements, the report will also estimate the site-wide average concentrations of Ra-226 (specifically, Bi-214).

2.5 System Sensitivity

The AMS can detect small changes in radiation over the detector footprint. For example, in other surveys of this type, landscape features such as wetlands are clearly detectable because of the shielding effects of water. Heavy vegetative cover can also reduce the amount of radiation reaching the detectors, usually because of the moisture present in leaves and other plant structures. The highest intensity naturally occurring gamma emissions are detected from bare or recently disturbed soil because the gamma emissions are not shielded from the detector. Concrete structures and buildings also show up clearly in the survey results because emissions from naturally occurring radioisotopes are present in construction materials and there is no vegetation to shield the emissions from the detectors. This correlation of survey results with identifiable surface features provides an additional quality check on the collected data.

A more detailed discussion of the detection limits for the various COPCs in this survey is provided in Section 3.

2.6 Data Analysis Algorithms

2.6.1 Gross Count Method

To obtain a gross count (GC) contour, the count data that will be collected by the AMS equipment will be first integrated between 38 and 3,026 keV:

$$C_G = \sum_{E=38}^{3026} c(E) \tag{1}$$

where

C_G = gross count rate (counts per second [cps]),
E = photon energy (keV), and
$c(E)$ = count rate in the energy spectrum at energy E (cps).

The system records gamma rays with energies up to 4,000 keV; however, there are very few gamma rays above 3,000 keV.

Since GC contours are meant only to depict terrestrial radiation levels, counts from cosmic radiation and airborne radon will be subtracted. Furthermore, the terrestrial GC rate will be converted to an exposure rate at 1-m (3.3-ft) height by applying a conversion factor. The calculations for the exposure rate, E_G, are summarized below. All counts will be normalized using detector live time:[1]

$$E_G = \frac{C_G - B}{S_f} e^{\mu(H-150)} \tag{2}$$

where

E_G = exposure rate from terrestrial gamma-ray emissions (μR/h),
B = background count rate from cosmic radiation, atmospheric radon, and aircraft materials (cps) (this parameter differs from total background radiation in that the latter includes all sources with the exception of anthropogenic contamination),
S_f = conversion factor (cps/μR h^{-1}),
H = aircraft's altitude (ft), and

[1] "Live time" is the amount of time over which the detector integrates readings.

μ = an attenuation coefficient (1/ft).

The background count rate from cosmic radiation, atmospheric radon, and aircraft materials will be determined as discussed above. The contours generated from these data will reflect the exposure rate at a height of 1 m from terrestrial sources (the background exposure rate will be subtracted).

The S_f factor in Equation 2 converts the count rate (cps) to an exposure rate (μR/h). The exponential term in Equation 2 corrects for changes in the attenuation of the gamma radiation in air because of slight variations in the aircraft's altitude. The attenuation coefficient, μ, will be obtained from experimentally measured data collected over the land test line during the survey.

The conversion from gross count to an exposure rate is based on the assumption that the source is spread uniformly over the width of the detector footprint, or field of view. Because of this assumption, the exposure rate will be underestimated over sources that are small with respect to the size of the footprint. For example, an intense point source of radiation can produce measured count rates at the detector equivalent to those from a much less intense large-area source. These issues and calculations are further discussed in Section 3.

GC data include contributions from natural sources of radiation. Consequently, these data include variations in terrestrial background radiation levels. Contours resulting from these variations in natural radiation often match specific surface features, such as tree lines, boundaries of cultivated land, and bodies of water, because of the different attenuation characteristics of the different materials. Exposure rate contours offer a sensitive means of identifying anomalous, potentially anthropogenic changes in the radiation environment, in addition to detailing variations in the natural background radiation emissions.

2.6.2 Man-Made Gross Count Method

The man-made gross count (MMGC) method is used to differentiate between anthropogenic radiation and naturally occurring radiation in a survey. The MMGC method, also referred to here as the MMGC filter, relies on the fact that most gamma-ray emissions from long-lived, anthropogenic sources of radioactivity occur in the energy region below about 1,400 keV. In areas where only natural sources of gamma radiation are present, the ratio of the counts appearing below 1,400 keV to those appearing above 1,400 keV remains relatively constant. This relationship is true even if natural background radiation levels vary by a factor of 10 across the survey area. If this ratio changes spatially, it is most likely because of a contribution from anthropogenic gamma radiation.

The MMGC algorithm is a means of identifying regions in the survey area where the shape of the energy spectrum deviates significantly from the shape of the background, or reference spectrum. The MMGC algorithm is very sensitive to small changes in the abundance of anthropogenic isotopes, while being very insensitive to large changes in the abundance of natural isotopes.

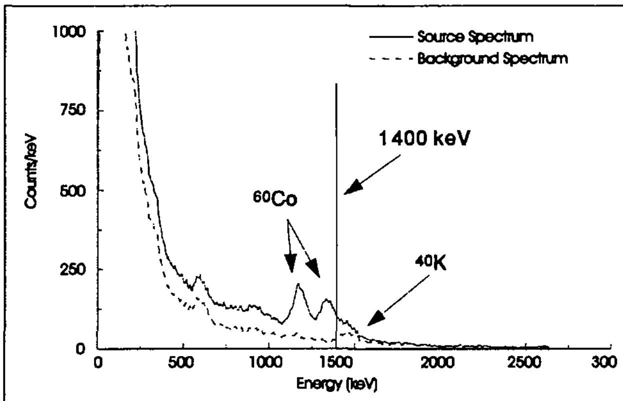

Figure 7 NaI Gamma Ray Spectrum Illustrating MMGC Energy Regions

Figure 7 shows two typical NaI gamma-ray spectra. Superimposed on a background spectrum is a spectrum obtained with cobalt-60 (Co-60) present. Counts from an anthropogenic radioisotope such as Co-60 fall almost entirely in the low-energy region below 1,400 keV. This condition is true for most anthropogenic radioisotopes of concern, which causes the ratio of counts in the low-energy range to counts in the high-energy range to change.

The normal ratio of counts in the low-energy region to counts in the high-energy region for a survey area is calculated from data obtained in an area that contains only natural sources of radioactivity. These counts are integrated over each energy region. To match the energy limits of the discrete channels of the acquired spectra, the low-energy region extends from 38 to 1,394 keV. The high-energy limits are then 1,394 to 3,026 keV. This ratio can be computed with Equation 3:

$$K_{MM} = \frac{\sum_{E=38}^{1394} c_{ref}(E) - B_{MML}}{\sum_{E=1394}^{3026} c_{ref}(E) - B_{MMH}} \qquad (3)$$

where

K_{MM} = ratio of low-energy counts to high-energy counts in the reference region of the survey,
B_{MML} = average background counts in the MMGC low-energy window (cps), and
B_{MMH} = average background counts in the MMGC high-energy window (cps).

The background count rates are derived from the flights as described in Section 2.6.1. These two background count rates remove the effect of non-terrestrial background from the MMGC extraction in a manner similar to the background removal in the GC algorithm. The subscript "*ref*" denotes that the counts in each channel, *c(E)*, are obtained from a reference area of natural background radiation. This ratio is applied to each second of data from the survey area:

$$C_{MM} = \left[\sum_{E=38}^{1394} c(E) - B_{MML} \right] - K_{MM} \left[\sum_{E=1394}^{3026} c(E) - B_{MMH} \right] \tag{4}$$

where

C_{MM} = anthropogenic (man-made) count rate (cps).

The MMGC algorithm allows the data to be analyzed such that variations in the count rate due to changes in natural background levels are filtered out. In regions with only natural background radiation, the MMGC algorithm will yield count rates that fluctuate statistically around zero. Variations in count rate due to anthropogenic or industrially enhanced radioisotopes then appear as isolated contours.

The increase in sensitivity obtained with the MMGC analysis over that of the GC method is significant. However, the MMGC filter is also sensitive to changes in the relative composition of natural background radiation. For example, areas where the aircraft's altitude changes significantly from the planned altitude and/or in areas exhibiting excess concentrations of natural potassium, uranium, and/or thorium, the ratio of the low-energy to high-energy gamma rays may be different, even though the gamma rays are emitted by naturally occurring radioisotopes. In such cases, the MMGC algorithm may generate a set of "false positive" anomalies on the MMGC contour map. A background-subtracted gamma energy spectrum (Section 2.6.4) in this case will only show natural radioisotopes or a smoothly varying background with no discernable peaks.

2.6.3 Isotope Extraction Algorithms

The algorithms employed in the search for particular isotopes are very similar to the MMGC algorithm. The major difference is that instead of using the full gamma-ray energy spectrum, they use only a few small portions of it. Two such algorithms are the 2-window algorithm and the 3-window algorithm.

2.6.3.1 The 2-Window Algorithm

The 2-window algorithm is the simplest of several window algorithms in use. It employs a narrow window centered on the energy of the specific photopeak of the isotope of concern. The algorithm assumes that the background counts in the photopeak window are proportional to the counts recorded in a background window located at higher energies. The background window may abut the photopeak window or may be separated from it in the energy spectrum. Note that the form of the equation for C_2 is identical in form to the equation for MMGC previously defined:

$$C_2 = \left[\sum_{E=E_1}^{E_2} c(E) - B_{2L} \right] - K_2 \left[\sum_{E=E_3}^{E_4} c(E) - B_{2H} \right] \tag{5}$$

with

$$K_2 = \frac{\sum_{E=E_1}^{E_2} c_{ref}(E) - B_{2L}}{\sum_{E=E_3}^{E_4} c_{ref}(E) - B_{2H}} \tag{6}$$

where

C_2	=	count rate from the 2-window algorithm (cps),
$c(E)$	=	count rate in the gamma-ray energy spectrum at the energy E (cps),
E_n	=	limiting energies of the windows ($E_1 < E_2 \leq E_3 < E_4$) (keV),
K_2	=	ratio of the counts in the photopeak window to the counts in the background window in the reference region of the survey area,
$c_{ref}(E)$	=	count rate in the reference gamma-ray energy spectrum at energy E (cps),
B_{2L}	=	average background counts in the 2-window low-energy window (cps), and
B_{2H}	=	average background counts in the 2-window high-energy window (cps).

The proportionality factor, K_2, is determined in a region of the survey that does not contain any of the specific isotopes of concern so that the photopeak window contains only background counts and, therefore, can be simply related to the number of counts in the background window. If the principal source of background gamma rays in the photopeak window is from scattered gamma rays from photopeaks at higher energies, this is a good assumption. If there are other isotopes with photopeaks in or near the photopeak and background windows, this algorithm fails.

2.6.3.2 The 3-Window Algorithm

If a reference region free of the specific isotope cannot be found or if the compositions of the other isotopes change drastically between the reference region and the rest of the survey area, then a simple multiplicative factor will not relate the counts in the photopeak window to the counts in the background window. To solve this problem, the 3-window algorithm employs a background window on each side of the photopeak window. (The two background windows generally abut the photopeak window in energy.) This algorithm assumes that for any spectrum, the number of background counts in the photopeak window is linearly related to the counts in the two background windows.

$$C_3 = \left[\sum_{E=E_2}^{E_3} c(E) - B_{3P}\right] - K_3\left[\left(\sum_{E=E_1}^{E_2} c(E) - B_{3L}\right) + \left(\sum_{E=E_3}^{E_4} c(E) - B_{3H}\right)\right] \tag{7}$$

with

$$K_3 = \frac{\sum_{E=E_2}^{E_3} c_{ref}(E) - B_{3P}}{\sum_{E=E_1}^{E_2} c_{ref}(E) - B_{3L} + \sum_{E=E_3}^{E_4} c_{ref}(E) - B_{3H}} \qquad (8)$$

where

C_3	=	count rate from the 3-window algorithm,
E_n	=	limiting energies of the windows ($E_1 < E_2 < E_3 < E_4$),
B_{3P}	=	average background counts in the 3-window photopeak window (cps),
B_{3L}	=	average background counts in the 3-window low-energy window (cps),
B_{3H}	=	average background counts in the 3-window high-energy window (cps), and
K_3	=	ratio of the counts in the primary window to the counts in the two background windows in a reference region of the survey area.

The 3-window algorithm is also very useful in extracting low-energy photopeak counts where the shape of the Compton-scattering contributions from other isotopes is changing significantly.

2.6.4 Gamma Spectral Analysis

The MMGC algorithm is very general and is sensitive to any change in the low-energy portion of the spectrum. It does not exactly identify the causes of the change — whether (1) a true anthropogenic isotope is present in this region, (2) the increased low-energy gamma rays are caused by naturally occurring isotopes whose gamma rays underwent more inelastic scatterings before reaching the detectors (for example, a change from a grassy meadow to a dense wooded area), or (3) the isotopic composition of the spectrum in this region of the survey is significantly different from where K_{MM} was determined (for example, granite versus limestone). Once a region appears in the anthropogenic contours, the energy spectrum is searched for individual isotopes. An analysis of the gamma-ray spectrum is used to identify the isotopes that are present in the spectrum and caused the MMGC deviation.

Generally, the large background field (from the naturally occurring isotopes) is not of interest — only the portion of the spectrum attributable to the anthropogenic isotopes is. Unfortunately, the number of counts at any given energy in a single 1-second measurement is so small as to make the identification of a particular isotope very difficult. To increase the number of counts in the spectrum being analyzed (and thus produce better statistics), the spectra from neighboring measurements are combined to produce a single spectrum showing the radiation measured over some larger area.

To determine net spectra at an identified anomaly, each area of interest is divided into "peak" and "background" regions. The contour levels used to define these regions are usually MMGC levels. The peak and background boundaries may be defined by other means (e.g., GC contour levels). The peak region of the spectrum consists of the spectra contained in the area bounded by the chosen contour level. The background region consists of the spectra contained outside the chosen contour level. This partitioning generally guarantees that the background spectrum is representative of the geology near the anomaly, but there will be some contribution of anthropogenic radioactivity in the background region.

This technique produces a net spectrum that has very little contribution from the naturally occurring radioisotopes in the region and makes the identification of the remaining isotopes fairly easy. The technique has one major drawback, in that it does not necessarily produce a true indication of the strength of the isotopes seen in the net spectrum. That is, comparing the intensity of an isotope in one net spectrum with the intensity of that same isotope in another spectrum may not be meaningful.

Numerous techniques can be used to scale the background spectra when creating the net gamma-ray spectra. One technique that will be used involves computing the ratio of the live times of the peak and background regions and using the results to normalize the data. This technique therefore creates a net spectrum by subtracting the background spectrum, normalized by the ratio of the peak live time to the background live time, from the peak spectrum:

$$c_{Net}(E) = c_{Peak}(E) - \frac{T_{Peak}}{T_{Bkg}} c_{Bkg}(E) \tag{9}$$

where

$c_{Net}(E)$	=	counts in the net energy spectrum at the energy E (cps),
$c_{Peak}(E)$	=	counts in the peak energy spectrum at the energy E (cps),
T_{Peak}	=	total spectrum live time composed of all peak-region spectra (s),
T_{Bkg}	=	total spectrum live time from all background-region spectra (s), and
$c_{Bkg}(E)$	=	counts in the background energy spectrum at energy E (cps).

This method of normalization is relatively straightforward to implement. If there is an excess of naturally occurring radioisotopes, the net spectrum will preserve the high-energy photopeaks of these isotopes.

Spectral Distortions. When the survey has been performed over an area exhibiting large, rapid variations in the elevation of the terrain, the net spectra can suffer from another type of error. In the case where the aircraft is flown at a constant elevation while passing over a canyon or begins to climb early to pass over a mountain, the added air mass distorts the gamma-ray spectrum by removing more of the low-energy gamma rays than the higher-energy gamma rays. If this increased altitude occurs in spectra that will be used to assemble the background spectrum, then the background will be slightly deficient in low-energy gamma rays. Subtracting the background from the peak spectrum will produce a net spectrum that has no discernable photopeaks but only a gently varying excess of low-energy gamma rays.

If the survey contains areas of very high activity, the count rate in the detectors may become high enough to distort the spectra. This distortion results from having insufficient time between the electrical pulses generated by the amplifiers on the photomultiplier tubes. When these pulses reach the data collector, one pulse is superimposed on the tail of another pulse, and the data collector determines a voltage for this combined pulse that is no longer characteristic of the individual pulses. At moderate count rates, this distortion may appear as a broadening of the photopeak widths and possibly as a shift in a photopeak's apparent energy. At very high count rates, these effects become more severe, and it may be nearly impossible to recognize any pattern to the photopeaks present in the spectrum. If the count rate in the 12-detector array is high and produces distorted spectra, then the analysis continues using the spectra collected by the single detector.

2.7 Methods to Estimate Soil Concentrations

The instruments used in this survey measure gamma-ray emissions, which directly correspond to exposure levels. However, many radiation-protection regulations are written in terms of soil activity levels rather than exposure levels, because soil activity levels are more commonly measured. Soil activity levels of concern are generally determined on the basis of human or ecological health risks, which, in turn, are directly related to exposures. These exposure estimates are computed from the soil activity level data on the basis of a number of assumptions.

The exposure data gathered during the pilot study aerial survey will be used to estimate what soil activity levels would result in these measured exposures through a similar, inverted process. By making assumptions about the distribution of the radioisotopes in the soil, soil activity levels that would provide equivalent measured exposures can be computed.

The conversion from a measured count rate to soil activity depends on several factors, including the distance from the source to the detector, the types and thicknesses of the materials between the source and detector, the size of the detector, and the distribution of the isotopes in the soil. For this aerial survey, all of these factors will be known with the exception of the source distribution in the soil. Table 3 gives typical conversion factors and minimum detectable activities (MDAs) for four possible distributions. The point source is assumed to be directly below the aircraft flight path. All of the other distributions vary only as a function of the depth in the soil. This topic is presented in more detail in Section 3.

Table 3 Minimum Detectable Activities (MDAs) for Bi-214 as a Point Source and Three Separate Soil Distributions

	Source Distribution[a]			
Parameter	Point Source	Uniform Depth	Exponential Depth[b]	Surface
Conversion factor	0.073 (mCi/cps)	0.064 (pCi/g/cps)	0.058 (pCi/g/cps)	0.014 (μCi/m^2/cps)
MDA	1.7 (mCi)	1.5 (pCi/g)	1.4 (pCi/g)	0.33 (μCi/m^2)

[a] Derived for a survey altitude of 46 m (150 ft) above ground level and a ground speed of 80 knots (92 mph).

[b] Where the distribution is of the form $A = A_0 e^{(-z/z_0)}$, with z_0 = 3 cm and the measured activity is averaged over the top 2.5 cm (1 in.) of soil.

Section 3
Data Quality Objectives

3.1 Introduction

A survey work plan, such as this document, is developed to provide detailed descriptions of all the instruments, methods, procedures, decisions, and plans that will be involved in a field data collection activity. The DQO process uses this information, along with information about the type of decision to be made, to determine if the field data collection activities and subsequent analysis methods produce data of sufficient quality to be used to support the required decision. The DQO process and discussion for the pilot study aerial radiological survey is presented in Section 3.2. This introductory section (Section 3.1) summarizes the information presented in Section 2 to provide a basis for the subsequent introduction and presentation of the DQO process.

Because this survey will use remote sensing equipment to gather data, it is inherently different from traditional field sampling programs. Field data collection efforts are generally described in detailed sampling plans that define and depict the various equipment, procedures, and methods that will be used to collect the samples. In addition, the locations, sizes, and types of samples are also described exactly. For this remotely sensed gamma-ray survey, descriptions of the equipment that will be used, how the system will be deployed, how data will be collected, and how the resulting data (computationally processed and analyzed in quantifiable terms) take the place of a more traditional sampling plan.

This survey is also different from traditional gamma walk-over surveys, where a site-specific background count rate is established and readings are compared to this rate to determine if they are significantly above background. For this survey, the natural isotopic ratios, specific to pilot study areas, will be calculated from the measurements over known background regions in the survey area. These ratios are used to detect changes in a specific isotope's abundance. Because site-specific isotopic ratios are the basis for analysis, the reliance on NIST-traceable sources for instrument verification during the survey is reduced. In fact, once the survey is started, data flights will be verified by measurements taken over a land test line established as part of the survey.

3.1.1 Sample Types

The field data that will be collected by the pilot study aerial radiological survey are instrumental readings rather than material samples. The readings that will be made as part of this survey contain two parts, (1) gamma spectral information spanning 0 to 4,000 keV and (2) positional information, both horizontal and vertical. These data are collected once per second as described in Section 2. Section 2 also contains descriptions of the relative accuracy and precision of these measurements. Section 2.7 gives an overview of the sensitivity of the system to various COPCs. The description of the types of readings that will be made and the equipment that will be used to make those readings is analogous to describing the samples in a more traditional sampling plan. These descriptions are provided in Section 2.

3.1.2 Sample Method and Procedures

The description of the detection system (the AMS) and the various flight parameters (speed, height, line spacing, etc.) are analogous to defining standard field sampling procedures (e.g., sample size, sampling methods, etc.). By specifying the altitude and speed of the aircraft, along with a description of the AMS system, the data collection activities are completely specified in quantifiable terms. How these instruments will be controlled is also described in Section 2. For example, systems that provide both horizontal and vertical control for the pilot are presented, and how deviations will be handled are also noted (e.g., Equation 2 will be used to adjust for variations in altitude that occur during a data flight). The role of an onboard technician to oversee and verify data collection is also described.

3.1.3 Sample Locations and Number

Data will be collected over the four pilot study areas shown in Figure 1 (see Section 1) covering a total area of 69,626 acres (108.8 mi^2). Sample lines will be flown at an average ground speed of 80 knots (nominally 135 ft/s) with a spacing of 76 m (250 ft). Data will be gathered once per second.

3.1.4 Quality Assurance Procedures

In many field sampling efforts, procedures such as splitting samples and providing trip blanks are used as quality control/quality assurance measures. For this survey, a land test strip or test line will be flown at the beginning and end of every data-gathering flight. This procedure provides two sets of quality control/quality assurance samples for every data gathering flight. These data will be used in two ways: (1) if variations between the data flights are minor and, based on the experience of the RSL mission scientist, within acceptable ranges, the data will be used to calibrate each data set, or (2) if the variations are significant, the area will be reflown. This procedure is analogous to providing trip blanks or duplicate samples in a standard sampling environment.

Several factors will be considered in selecting the land test line for the aerial survey. The primary factor is that the terrestrial gamma radiation over the test line (about 1.6 km [1 mile] in length) should be relatively constant. A secondary factor is the desire to have visual references for the flight crew to guide them along the test line (such as a power line or a fence row). A third factor is the desire to avoid inhabited areas. Since the test line will be flown at the survey altitude twice on every flight, flying over inhabited areas could cause many complaints.

The land and water test lines will be flown and measurements taken at the beginning and end of each flight, and the average net count rate over the test line (land minus water background count rates) will be calculated from these measurements. For each flight, this average net count rate will be compared with the average of all prior test line count rates (C_{ave}). If the count rate of the new line differs by less than 200 counts (about 0.2 μR/h) from C_{ave}, the system will be judged to be working correctly. If the count rate is outside of that range, then the system will be inspected and tested on the ground before any more data are collected.

Using altitude spirals to determine the contributions to the survey from atmospheric and cosmic sources and obtaining confirmatory measurements with ground-based gamma-spectroscopy instruments are analogous to using standards and duplicate sampling methods in a more traditional field sampling program.

In addition to these procedures, once a data flight is complete, the data are immediately evaluated to determine if problems existed during the flight. Within a short time of a flight (typically, 40 min), a visual examination of the data will be completed in the data center. Preliminary data analysis will also be performed on-site. In addition to providing a quality assurance/quality control function, this rapid on-site data screening will allow sampling procedures to be changed or the area reflown if questionable results are obtained.

3.1.5 Data Analysis

Typical sampling plans require the description of the laboratory (or field) data analysis methods and the equipment that will be used. For the data acquired during this survey, the data analysis equations presented are analogous to laboratory methods and describe completely how the data will be processed.

Once the data are processed through one of the analysis equations (gross count, man-made gross count, 2-window, 3-window, etc.), the processed data in regions without anthropogenic influences are approximately normally distributed. Using statistical analysis, any values in these distributions that appear anomalous can be classified as "anomalies." In evaluating the data populations that result from these analyses, an appropriate threshold can be established. Typically for aerial surveys with the AMS, any data that are more than three standard deviations (3σ) from the mean are classified as anomalies. However, spatial patterns also need to be evaluated to determine whether the data actually represent potential anomalies in the field or are part of the normal distribution of background values. Additional processing will be done in areas with potential anomalies, as described in Section 2.6.4

The analyses for the pilot survey data will be described in the final report. The work plan describes these general procedures; specifics can not be provided until the data are processed to determine the resulting distributions and any spatial correlations.

3.1.6 Potentially Impacting Factors

Factors that could potentially affect survey results are the detection system, the speed of the aircraft, the altitude of the aircraft, contributions from cosmic sources, and variations in shielding (e.g., vegetation cover or soil moisture). These are all discussed in detail in Section 2, including presentation of the equations that will be used to account for variations in altitude and other survey parameters. In particular, Section 2.6.4 provides specific information on how spectral distortions are analyzed. Section 2 also contains detailed descriptions of the data collection systems, including information on the relative accuracies of the measurements from these systems.

Standard walk-over radiological surveys utilize a "typical area background" (TAB) value as the basis for evaluating point-by-point measurements. Counts higher than the TAB are declared as "anomalous" or "above background" while counts lower than the TAB are declared as "no counts above background." Unfortunately, observed counts in nature vary greatly about the TAB, even in the absence of anthropogenic isotopes. If tolerances are set low, this natural variability creates erratic (false) positive and negative results. If tolerances are set high, to avoid false indications, many anthropogenic contributions will be missed. Sophisticated gamma spectral processing of the aerial measurements data will greatly improve detectability of anthropogenic contributions by removing the highly variable natural background counts on a point-by-point basis. Examples of beneficial results are: anthropogenic contributions in low background areas will not be ignored, and high natural background areas will not trigger erroneous anthropogenic indications.

As described in Section 5, the RSL Mission Scientist will have on-site decision-making authority during the survey. Before each data flight, the Mission Scientist will consider site environmental conditions, weather, equipment, and other variables with regard to how these factors could affect data quality (the Pilot-in-Command will make safety decisions concerning the aircraft and flight safety operations). The Mission Scientist will direct the data gathering flights using these site-specific factors and technical expertise.

3.1.7 Qualitative and Quantitative Descriptions

This work plan quantitatively defines all of the parameters related to the pilot study aerial radiological survey. Specific values for speed and altitude have been established, as have descriptions of the AMS. In addition to these items, the data analysis procedures have been described quantitatively, in the form of the equations that will be used, and qualitatively, in descriptions of why and how each equation will be used.

Descriptions of how the resulting data will be used for decision making are provided in a more qualitative fashion in Section 3.2, in keeping with the preliminary nature of this survey. This qualitative approach is in accord with EPA DQO guidance.

The EPA document, *Data Quality Objectives Process for Hazardous Waste Site Investigations* (EPA 2000a), states:

> *"The DQO Process has both qualitative and quantitative aspects. The qualitative parts promote logical, practical planning for environmental data collection operations and complement the more quantitative aspects. The quantitative parts use statistical methods to design the data collection plan that will most efficiently control the probability of making an incorrect decision.... Although the statistical aspects of the DQO Process are important, planning teams may not be able to apply statistics to every hazardous waste site investigation problem. For example, in the early stages of site assessment*

[e.g., RCRA Facility Assessments, Superfund Preliminary Assessments/Site Inspections (PAs/SIs)], statistical data collection designs may not be warranted by program guidelines or site-specific sampling objectives. In some cases, investigators may only need to use judgmental sampling or make authoritative measurements to confirm site characteristics."

The pilot study aerial radiological survey fits this description quite well. It is a preliminary survey in the early stages of a site assessment. It is premature to specify exactly how the data gathered during this process will be used. It is important, however, to specify exactly how the data will be gathered, processed, and analyzed, so future decisions about the appropriateness of the data to a specific decision can be ascertained. This document provides that information. Additional site- and data-specific information will be contained in the final report.

3.2 DQO Process and Application

The DQO process is a series of planning steps based on the scientific method for establishing data quality criteria and for developing survey designs (EPA 1994, 2000b). The DQO process provides a systematic approach for defining the criteria necessary for a successful survey. As described in the *Multi-Agency Radiation Survey and Site Investigation Manual* (EPA 2000b), the DQO process is an important part of the planning phase of the data life cycle for radiological surveys conducted in support of characterization efforts. DQOs are developed for each phase of the radiation-survey and site-investigation process by using a graded approach.

A graded approach to DQO development allows for the collection of different types of data during each phase of the site investigation process on the basis of the specific decisions that are anticipated during each phase. As the site investigation and cleanup processes progress, DQOs become more specific and rigorous, usually with statistical limits on decision errors as the process is completed and final status surveys are designed and conducted. Because the pilot study aerial radiological survey is being conducted in support of the early phases of site investigation, the DQOs outlined in this document focus on supporting initial site investigation decisions. This support covers decisions on whether to further investigate anomalies identified during the survey and decisions on which areas are considered impacted or unimpacted by radioactive materials. The information gathered and data collected by this survey will only be part of the information considered when making these decisions.

The DQO process consists of the following seven steps:

1. State the problem,

2. Identify the decision,

3. Identify the inputs to the decision,

4. Define the study boundaries,

5. Develop the decision rule,

6. Specify tolerable limits on decision errors, and

7. Optimize the design.

The following sections discuss the steps of the DQO process as they relate to the pilot study aerial radiological survey for Polk and Hillsborough Counties, Florida.

3.2.1 State the Problem

Aerial radiological survey data are needed to assess the potential for human exposures to excess levels of gamma radiation and radon gas for individuals residing in dwellings constructed over formerly mined phosphate lands in central Florida. Aerial measurements of gamma exposure rates will be the primary screening tool to determine if areas have been impacted by elevated levels of radioactivity sufficient to warrant further actions.

3.2.2 Identify the Decision

The primary decision that the aerial radiological survey will support involves determining whether additional investigation is needed for residential areas within the formerly mined phosphate lands (i.e., whether there are anomalies associated with gamma-emitting radionuclides [e.g., Ra-226 and decay products] that indicate the need for further investigation). Evaluation of anomalies detected will include a review of the total radiation exposure rate, the man-made gross count (MMGC) rates, and the isotopic-specific data for gamma energies associated with Ra-226 (specifically, Bi-214).

The decision to conduct further investigation will be based primarily on the results of the external gamma exposure rate measurements. Average exposure rate measurements of 20 μR/h above background will indicate the need for further investigation activities. This exposure rate criterion is based on the Uranium Mill Tailings Radiation Control Act (UMTRCA) limit of 20 μR/h above background for indoor gamma radiation exposure.

3.2.3 Identify the Inputs to the Decision

The primary inputs to the decision will be the raw data (including ground-truth measurements) collected as part of the aerial survey and historical site information, including aerial photographs and GIS layers. The aerial survey data will be evaluated and presented on maps for use in decision making related to follow-up investigations. The following types of figures represent anticipated inputs for decision making:

- Plots of total exposure rate (μR/h),

- Plots of MMGC and/or man-made exposure rate (apparent), and

- Plots of the calculated average soil concentrations or excess levels (count rates) of the gamma energy associated with Ra-226 (specifically, Bi-214).

3.2.4 Define the Study Boundaries

For this aerial radiological survey, the study area boundaries are determined generally by former phosphate mining areas within Polk and Hillsborough Counties (including the currently operated Tenoroc mine). The specific boundaries of the four pilot study survey areas are shown in Figure 1, with their median latitude-longitude coordinates provided in Table 1 (see Section 1).

3.2.5 Develop the Decision Rule

If the inferred aerial terrestrial exposure rate in a survey area exceeds 20 μR/h above background or exhibits excess levels of Bi-214 activity, then the area will be flagged as a candidate for further investigation. The 20 μR/h above background criterion represents the outdoor gamma exposure rate in excess of background.

If the data show no evidence of average exposure rates greater than 20 μR/h above background or excess Bi-214 activity, additional investigation will not be required, unless other historical data suggest possible impacts from phosphate mining activities (e.g., elevated indoor Rn-222 measurements).

The technology used for this survey represents the state of the art for rapid survey and detection of gamma-emitting radionuclides from large land areas by using an airborne survey platform. For many radionuclides, this system is capable of detecting radioactivity at levels approximately equal to the naturally occurring average background levels. Because the helicopter must operate at an established safe height and speed, and because the field of view of the detector system is relatively wide, the ability to detect small areas ("hot spots") of low-yield gamma emitters is limited.

Specific detection levels are discussed in more detail in Section 3.2.6, but for decision-making purposes, the system is best used for contamination conditions that result in large area sources of gamma emitters (e.g., airborne releases, spills, or fallout). Because the capability for detecting small discrete areas of elevated radioactivity is limited, and because final cleanup guidelines (with associated size and averaging requirements) have not been established, the aerial measurement data should, in most cases, be supplemented with historical process information prior to determining that an area is unimpacted by radioactive materials.

3.2.6 Specify Tolerable Limits on Decision Errors

Areas exhibiting inferred surface gamma exposure rates greater than 20 μR/h above background will be flagged for further investigation in future studies.

The nominal MDA for the aerial system at the 95% confidence level for areas large in relation to the detector footprint ("infinite") is approximately 2.5 μR/h, well below the 20 μR/h above background threshold level. However, MDA is not the only consideration in identifying surface level exposure rates.

Because the inferred surface exposure rate measured by the aircraft is an average over the nominal surface footprint of the detector system, observed aerial values are a function of both the surface exposure rate and the size of the surface area. For areas that are not "infinite," significant correction factors apply. Therefore, an observed measurement just above the MDA of 2.5 μR/h may imply a surface deposition of part of the detector footprint at or even well above the 20 μR/h above background threshold. Only when the uncorrected observed aerial exposure rate is above 20 μR/h can one be certain that at least some portion of the detector footprint exceeds 20 μR/h.

In order to determine the applicable correction factor, the extent of the surface area must be determined from the measured spatial data. In principle, this may be done by calculating the surface extent using the measured spatial extent and the known detector footprint. In practice, as the surface extent becomes small relative to the detector footprint, there will be very little difference between the known detector footprint and the observed aerial pattern. At some point, the observed spatial uncertainty will exceed the real differences between the detector footprint and the observed pattern, thus making a computation of input surface extent impossible. Even when observable differences exist between the observed data and detector footprint, observed errors may be magnified tremendously.

The overall uncertainties in categorizing surface areas as having inferred exposure rates either below or above the 20 μR/h threshold is complex and is very dependent on the characteristics of the surveyed area. There will always be some areas that will not be clearly in the below or above class but will be in a "maybe" class. The size of the "maybe" class cannot be determined until the data is acquired and analyzed. In a somewhat similar survey for the abandoned uranium mines in the Navajo Nation (Hendricks 2001), 7,674 square miles of suspect areas were surveyed. Of this area, 101 square miles (1.3%) were identified as either above or "maybe" areas, reducing the areas requiring surface investigation by a nominal factor of 76. It is anticipated that similar results will be obtained in the Florida pilot study survey.

Also see Section 3.3 for a discussion and examples of concentration estimations.

Investigation levels for the total gamma exposure rate and excess Bi-214 activity measurements will be based on the background levels for these parameters. The investigation levels for specific radionuclides are based on the uniform soil detection levels (MDAs) for the aerial measurement system shown in Table 4. The primary contaminant of concern for this pilot study is Ra-226. For Ra-226, the system MDAs are very close to the background levels of this radionuclide. However, the MDAs are low enough to provide useful information concerning the need for follow-up investigation, and the algorithms discussed in Section 2 provide a method for determining whether measurement results near background for Ra-226 appear anomalous.

The example detection levels shown in Table 4 are based on estimated sensitivity values for the aerial measurement system. Detailed calculations using site-specific data will be performed following the field measurements, and final detection levels based on these calculations will be provided in the final survey report.

Table 4 Estimated Aerial Survey Sensitivity[a]

	Point Source MDA[b]			
Nuclide (+ progeny)	No offset (mCi)	Midway (mCi)	Uniform Soil[c] (pCi/g)	Surface Deposition (μCi/m^2)
^{226}Ra[d]	1.7	4.9	1.5	0.33

[a] Twelve 16- x 4- x 2-in. NaI(Tl) detectors, 150 ft AGL, 250 ft spacing, 80 knots ground speed.

[b] Can be total of fragments within detector's field of view, whose radius is approximately the altitude AGL.

[c] Other depth profiles generally have greater sensitivity, but overburden will hamper sensitivity.

[d] Ra-226 MDAs based on detection of Bi-214 in assumed equilibrium with parent Ra-226.

All of the sensitivities cited above are for concentrations in excess of the natural background. In other words, the soil activity is the sum of the concentration detected in the aerial survey plus the average concentration in the survey area. This sum is calculated for each radionuclide. The average abundance will be estimated from the set of judiciously selected, ground-based corroborative measurements.

3.2.7 Optimize the Design

As data are collected and analyzed, the estimates of system performance outlined in this plan will be reviewed and updated using actual site-specific data. If significant deviations are noted from the performance estimates shown in this plan, the data will be reviewed to determine the causes for the deviation as well as possible methods (e.g., adjusted flight parameters) to change survey protocols to meet the original performance estimates. As an example, actual detection levels for Ra-226 (based on Bi-214) will be calculated using data from the background areas established for this survey. These levels will be compared to the estimated values shown in Table 4 as part of the daily data evaluation process. If the actual detection levels exceed those estimated in Table 4, consideration will be given to adjusting flight parameters and data collection methods to reduce the detection levels. If such optimization is not possible due to safety, cost, or other considerations, the EPA Project Manager will be notified, and the rationale for continuing with adjusted detection levels will be documented in the final report.

3.3 Examples of Concentration Estimations

Since the detectors employed on the aerial system are not shielded, the detector footprint (field of view) has no firm boundary. The main factors that define the footprint are the energy of the gamma rays and the attenuation of the gamma rays by the atmosphere. The detector array is thus capable of detecting gamma rays from large distances, but atmospheric attenuation acts to shield gamma rays from large distances.

The conversion factors used for converting the measured count rate into activity concentrations are based on calculations that assume the radioactivity is uniformly dispersed over an area on the ground that is "large" compared to the field of view of the detector array.

The field-of-view calculations are based on integrating the number of gamma rays from a small radioactive source element at location r with activity $n(r)$ gamma rays per second. This initial flux is decreased by the fraction intercepted by the detector (the $A(E)/4\pi d^2$ factor) and the attenuation through the soil and atmosphere (the exponential term):

$$c(E) = \int n(r) \frac{A(E)}{4\pi d^2} e^{\left[-\left(d\left\{\frac{\mu}{\rho}\right\}_{air} \rho_{air}\right)\left(z \sec(\theta)\left\{\frac{\mu}{\rho}\right\}_{soil} \rho_{soil}\right)\right]} dV \qquad (10)$$

where

$c(E)$ = count rate in the photopeak at energy E,

$n(r)$ = activity of the small source element in volume dV,

$A(E)$ = effective area of the detector at energy E,

d = distance between the source element and the detector,

z = distance of the source element below ground level,

θ = angle formed at the detector between the source element and the perpendicular to the ground,

$\left\{\frac{\mu}{\rho}\right\}_{air}$ = mass attenuation coefficient for air,

ρ_{air} = density of air,

$\left\{\frac{\mu}{\rho}\right\}_{soil}$ = mass attenuation coefficient for soil, and

ρ_{soil} = density of soil.

First, define the distance between the source element and the detector as two components: (1) a vertical distance, $h + z$, composed of the height of the detector above the ground and the distance of the source element below ground level, and (2) a horizontal distance, r.

For a uniform surface distribution of a radioactive isotope ($z = 0$), the equation becomes:

$$c(E) = \frac{S_0 A(E)}{4\pi} \int_0^\infty \frac{1}{d^2} e^{-\left(d\left[\frac{\mu}{\rho}\right]_{air} \rho_{air}\right)} 2\pi r \, dr \qquad (11)$$

where

S_0 = surface activity and

r = horizontal distance of the source element from directly below the detector.

If the source area extends only a finite distance from the origin (instead of the infinite distance shown), Equation 11 can produce the count rate if the upper limit of the integral is changed to reflect the radius of the source. Figure 8 and Table 5 present the results of these calculations that compare the effect of changing the size of the source area. A spot size with a radius of 1,000 m approximates the "infinite" area used by the other calculations, and this spot size is given a correction factor of 1.0. The factors in the table multiply the activity value generated by the "large" area calculations. In other words, if the detector count rate in the Bi-214 photopeak for one second indicates that the large area activity is X pCi/g, then a small spot with a 10-m radius (directly beneath the aircraft's path) and an activity of $41.3 \times X$ pCi/g would also produce that count rate.

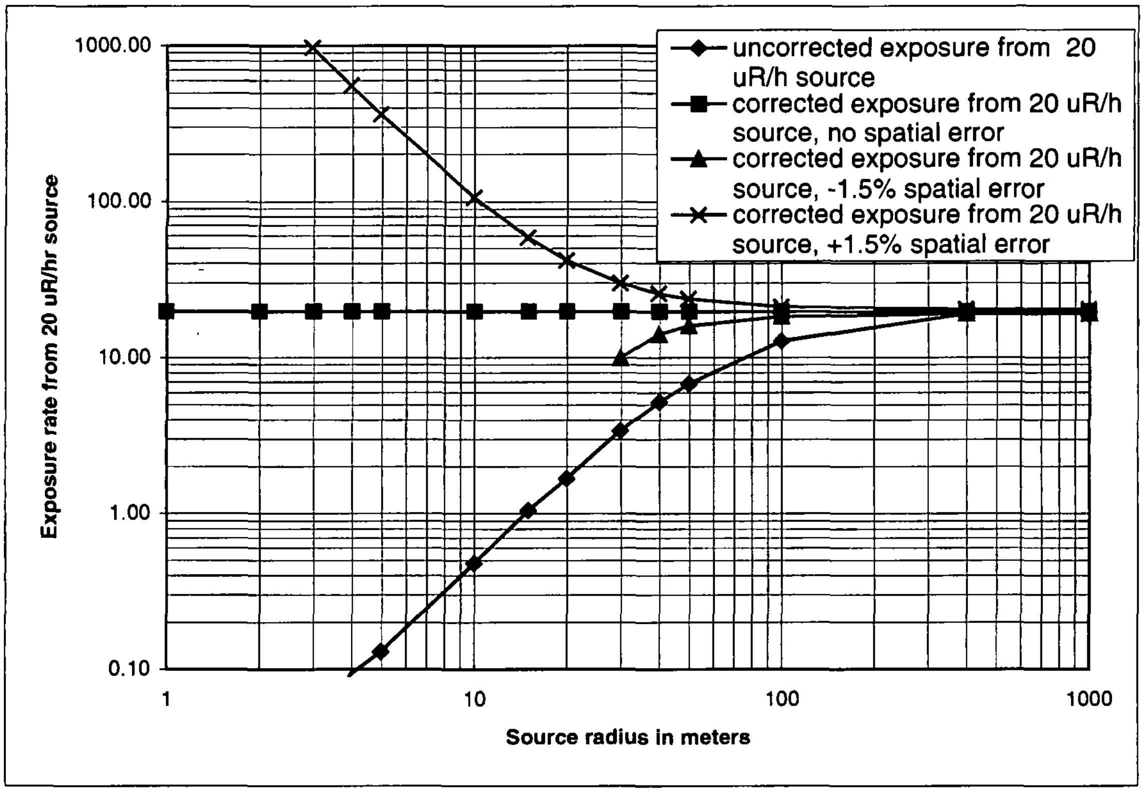

Figure 8 Observed Exposure Rate versus Source Radius Size

Table 5 Finite Size Corrections for Bi-214

Correction factors and predicted exposure level (Equation 11)					Prediction of aerial pattern radii with -1.5%, 0%, and +1.5% errors			Prediction of corrected aerial exposure with error propagation due to radii errors of -1.5%, 0%, and +1.5%		
					Observed Output Radius			Corrected Aerial Exposure from 20 μR/h Source		
Source Radius (meter)	Source Size (acres)	Correction Factor Bi-214	Source Exposure which gives 20 μR/h Uncorrected Aerial Exposure[a]	Uncorrected Aerial Exposure from 20 μR/h Source[b]	Minimum[c,f] (-1.5% error)	Average[d] (no error)	Maximum[e] (+1.5% error)	1.5% (low) Aerial Error[f]	No Aerial Error[g]	1.5% (high) Aerial Error[h]
1000	776	1.00	20	20.00	992.29	1007.17	1022.28	19.40	20.00	20.61
400	124	1.03	21	19.42	411.44	417.61	423.88	19.36	20.00	20.66
100	7.76	1.55	31	12.90	153.90	156.20	158.55	18.57	20.00	21.47
50	1.94	2.9	58	6.90	128.08	130.00	131.95	16.03	20.00	24.09
40	1.24	3.79	76	5.28	124.62	126.49	128.39	14.13	20.00	26.04
30	0.7	5.8	116	3.45	121.87	123.69	125.55	10.02	20.00	30.28
20	0.311	11.8	236	1.69	~~119.86~~	121.66	123.48	~~-1.71~~	20.00	42.37
15	0.175	18.9	378	1.06	~~119.15~~	120.93	122.75	~~-18.14~~	20.00	59.29
10	0.078	41.3	826	0.48	~~118.64~~	120.42	122.22	~~-65.08~~	20.00	107.65
5	0.019	153	3,060	0.13	~~118.33~~	120.10	121.91	~~-318.56~~	20.00	368.80
4	0.012	213	4,260	0.09	~~118.29~~	120.07	121.87	~~-508.68~~	20.00	564.65
3	0.007	527	10,540	0.04	~~118.26~~	120.04	121.84	~~-919.41~~	20.00	987.80
2	0.003	1,030	20,600	0.02	~~118.24~~	120.02	121.82	~~-2,092.94~~	20.00	2,196.80
1	0.001	2,900	58,000	0.01	~~118.23~~	120.00	121.80	~~-8,430.00~~	20.00	8,725.40

[a] Uncorrected observed 20 μR/h always indicates surface exposure levels greater than 20 μR/h. High confidence region.

[b] MDA of 2.5 μR/h occurs at a surface deposition radius of ~27 meters. This is the smallest area that can be detected at a surface exposure of 20 μR/h. Smaller areas would have to be higher than 20 μR/h to be seen as a surface level greater than the system MDA.

[c] Observed output radii less than the detector footprint radii are due to measurement uncertainty and are physically unrealizable. Calculation of the surface radius (and associated correction factor) cannot be done.

[c,d,e] Note that the observed output radius is nearly equal to the surface radius for large surface areas and is nearly equal to the detector footprint radius for small surface areas.

[f] Negative aerial exposure rates come from physically unrealizable observed radii. Negative values are shown lined out to indicate that these numbers are not meaningful for correction purposes.

[f,g,h] Extremely small (1.5%) errors in the observed data create very large errors in the corrected surface exposure rate. This creates uncertainties in the process of estimating true surface exposure rates.

Section 4
Quality Assurance

All survey work will be performed in accordance with applicable Bechtel Nevada Integrated Safety Management policies, procedures, and rules. Normal aerial radiological survey quality assurance and data validation procedures will be performed in accordance with the *RSL Aviation Services Operations Manual* and the *AMS Helicopter Consequence Management Mission* Operational Procedure, OP-2200.241. These procedures, which are summarized in Sections 2 and 3.1.4 of this plan, include (but are not limited to):

- Data quality analyses utilizing pre- and post-flight validation routines,
- Analysis of land test and water line normalization data,
- Reflight of lines or areas where the collected data does not meet quality requirements,
- Generation of exposure rate and excess bismuth contour maps in the field to determine overall end-to-end quality and completeness of coverage, and
- Generation of gamma energy spectral data plots and report summaries.

The data-evaluation, data-management, text-revision, and records-retention activities associated with development of the final report will be conducted under the Argonne National Laboratory QA program. The purpose of the QA program is to establish procedures for performing high-quality work on projects and to ensure that the planned procedures are being followed during the course of the work. The work on this project will be conducted in accordance with the Quality Assurance Plan for the Environmental Assessment Division, which implements the requirements of DOE Order 414.1A, "Quality Assurance."

Section 5
Project Management

5.1 Project Institutions

This project will be managed by Joseph Ginanni, DOE National Nuclear Security Agency. At RSL-Nellis, the Remote Sensing Department will be responsible for project management and the Radiation Sciences Section will be responsible for the field work associated with this project. The RSL-Nellis Mission Scientist will be David Colton, who reports directly to Clifton Bluitt, Manager of the Radiation Sciences Section. The Environmental Assessment Division at ANL will be responsible for project management at ANL and for preparation of the final report. The principal investigator from ANL will be George Stephens, who reports directly to Dr. David Miller, Manager of the Geoscience and Information Technology Section, in the Environmental Assessment Division.

5.2 Project Time Frame

The survey is currently planned for May 17 to June 2, 2004, with ten good flying days required during this period to complete the survey. However, if these dates are not satisfactory, and the team is not already in the field, later dates can be considered.

The current schedule calls for flights to begin on Wednesday, May 19. The initial flights will include the site reconnaissance survey, a perimeter flight, an altitude spiral, and the start of data collection flights (which include flights over the established land and water test lines). The altitude spiral will also be flown over the established land and water test lines. A typical data gathering flight lasts for two and one-half hours.

Table 6 describes a typical day. This includes the calibration procedures, data analysis, and data flights. Days may differ from this schedule based on need, weather, or other conditions.

Table 6 Typical Daily Activities

Time	Activity
07:00	Mission team reports to work at the Fixed Base Operator (FBO).
	Daily mission safety briefing.
07:30	Electronic Technicians start calibration and collect preflight.
	Pilots and Aircraft Mechanic start aircraft preflight checks.
08:00	Data Tech runs preflight; Mission/Data Scientists review results.
08:30	Mission/Data Scientists brief pilots and flight Electronic Tech.
09:00	1st flight departs.
11:30	1st flight returns.
	Lunch; refuel and prepare for 2nd flight.
13:00	2nd flight departs; initiate data processing for morning flight.
15:30	2nd flight returns.
	Process data from afternoon flight; prepare for next day's flights.
16:30	End-of-day meeting held.
	Data Tech assembles analysis for overnight processing.
17:00	Mission team departs FBO.

5.3 Environmental Factors

The mission scientist from the RSL will make the decision as to whether or not to fly on each day on the basis of site environmental factors. There are several environmental parameters that could potentially impact the survey and influence the survey data. For example, rain, standing water, or saturated surface soils can affect gamma-ray measurements. These factors all relate to the amount of water present between the radionuclides in the soil and the detectors.

The amount of water in the soil varies greatly under normal conditions. Regions that are near river beds or are constantly irrigated tend to have naturally high water content. Soil in the desert has a very low level of moisture. The decision on whether or not to fly will be based on an increase from this "normal" level of soil moisture. If there is more than one-tenth of an inch of standing water, or the soil is more than 20% saturated (about the moisture content of clay), the measurements of gamma-ray activity will be significantly affected from their normal values. Since the "thickness" of this layer of water between the soil and the detectors probably varies greatly over the footprint of the measurement, there is no consistent method to correct for the excess water. At these levels, the Mission Scientist will decide not to fly over the regions affected by the water. This decision may be made on the basis of weather reports, driving around the survey area, or personal inspections of handfuls of soil in several locations.

5.4 Safety Factors

The Pilot-in-Command from the RSL will make decisions during each flight as to whether flight conditions are safe, on the basis of local actual and expected conditions. For example, winds that are more than 30 knots or that gust by more 15 knots typically represent a safety concern. However, the Pilot-in-Command can terminate flights on the basis of any conditions deemed unsafe.

5.5 Early Project Termination

If the survey has experienced a series of delays due to weather, equipment problems, or priority assignments (e.g., national security), the Mission Scientist from the RSL will consult with the EPA Project Manager to determine the appropriate actions.

Section 6
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Appendix A: Radioactivity and Radiation

This appendix contains a brief introduction and discussion of radioactivity and radiation to provide a background for discussions of the aerial radiation survey methods and results. Naturally occurring and anthropogenic radioisotopes, including natural background radiation levels, are discussed. The discussion includes explanations of radiation exposure and radiation dose.

A.1 Radioactivity

An element of a particular type consists of atoms that have the same number of protons (i.e., positive nuclear particles). The atoms can differ in the number of neutrons within the nucleus. These different nuclear species of an element are called isotopes (Cember 1988). Most elements have several isotopes. While differing numbers of neutrons do not affect the chemical properties of these elements, their stability can be affected. If the number of neutrons versus protons lies outside a relatively narrow range, the isotope will be unstable and be prone to break apart (decay). An isotope that is prone to decay is commonly referred to as a "radioisotope" because it is radioactive (emits radiation as it decays). Radiation is energy traveling in the form of waves or rays (such as gamma-ray photons) or particles (such as alpha or beta particles).

In many cases, radioisotopes undergo a series of transformations until a stable isotope is reached. This series of transformations is called a decay chain or series. The different elements that result from these transformations are called progeny or daughter products. Each isotope in these chains has its own characteristic radiation emissions, releasing radiation of a specific type and energy.

The more abundant types of radiation are gamma rays, beta particles, and alpha particles. An alpha particle is composed of two protons and two neutrons. Alpha particles can be stopped (shielded) by a single sheet of paper. A beta particle is a negatively charged electron emitted from the nucleus. Beta particles are more penetrating than alpha particles, but are also quickly attenuated in the environment. For example, beta particles can be stopped by a thin sheet of aluminum or by a few centimeters of water. Unlike alpha and beta particles, gamma radiation has no mass and no charge. Gamma radiation can pass through paper, aluminum, or even several centimeters of lead, and is thus more easily detected by remote sensors (sensors that can detect radiation at a large distance from its source) than are alpha and beta particles. This report focuses on gamma radiation.

The characteristic gamma emissions (defined by energy levels) for different isotopes are well known and form the basis for using remote sensing devices to detect the presence of a particular isotope. The detection efficiency of remote detection devices depends on the energy of the gamma ray and the amount and type of matter between the decaying isotope and the detector. For example, soil and water are good shielding materials. Gamma-ray emissions can be stopped by several inches of either, preventing human exposure to potentially damaging radiation (but also preventing remote detection). In contrast, air does not attenuate gamma radiation as quickly, allowing detection of radioactive materials with remote sensing devices.

For some radioisotopes of concern, such as those in natural uranium, the energies of the gamma emissions are difficult to detect. However, for many of these isotopes, the decay of one of its progeny generally provides a more easily detected gamma emission. These emissions can then be used to determine the amount of the original isotope present. Natural uranium is typically detected by the gamma emissions from the decay of protactinium-234m (^{234m}Pa), a uranium-238 (^{238}U) progeny product with a half-life of slightly more than 1 minute. Similarly, Ra-226 is often detected using the gamma emissions of bismuth-214 (^{214}Bi) or lead-214 (^{214}Pb), two of its radioactive progeny.

A.2 Activity, Exposure, and Dose

Radiation is measured and reported in a number of different ways, depending on the way the measurements were made and their intended use. "Activity" relates to the rate of isotopic decay. Activity units are used when the concentrations of radioactive materials are needed. Because of the difference in the rates of decay of isotopes, mass measurements (grams) are not useful for quantifying these materials. Instead, the measurement unit needs to be based on the decay rate. It is measured as the number of disintegrations per unit time. A typical activity unit is the curie (Ci). It is equal to the activity of 1 gram of radium-226 (^{226}Ra). The international unit equivalent is the bequerel (Bq), which is defined as 1 disintegration per second. The activities of various isotopes can be measured in the laboratory from field-collected samples of soil, sediment, or water. These isotope-specific activities are then used in risk assessments to derive cancer risk estimates. They can also be used to derive estimates of the amount of radiation energy absorbed by a given mass of tissue, which determines the amount of damage done to that tissue. The amount of energy absorbed by tissue from an exposure is called a "dose." Typical dose units are the rad and the gray (Gy).

When the effects of radiation are being measured in the environment, as opposed to measurements made in the laboratory, exposure is generally measured directly. The detectors used in this survey measured the amount of gamma radiation striking them each second. This value was then converted into an "exposure rate." The typical unit of exposure is the roentgen (R), which is a measure of the amount of radiation absorbed by a given volume of air. Measurements in this report are given in microroentgens (μR). A microroentgen is 1/1,000,000th of a roentgen. Exposure measurements provide a means of comparing ambient radiation levels across large areas to determine if further investigation is required. Typically, occupational exposure level calculations use roentgens as a general exposure unit.

A.3 Natural and Anthropogenic Radioisotopes

A.3.1 General

Radiation comes both from natural sources (i.e., cosmic rays or terrestrial materials) and, potentially, from anthropogenic (man-made) radioactive isotopes. As noted previously, most natural elements have a number of isotopes, some of which are radioactive and subject to decay. Naturally occurring radioactive materials are found everywhere in the environment. Anthropogenic isotopes, on the other hand, are in the environment because of their manufacture, use, and disposal by humans.

Many components contribute to forming the total gamma-ray energy spectrum to be measured by the sensors that will be used in this study. These components are (1) natural terrestrial radionuclides, (2) airborne radon gas and its progeny, (3) cosmic rays, (4) anthropogenic terrestrial radionuclides, and (5) contributions from equipment that will be used in the study.

The first three components are considered to be natural background radiation. The anthropogenic radionuclides (such as cobalt-60 [^{60}Co] and cesium-137 [^{137}Cs]) are often the components of the most interest in environmental surveys. In this study, naturally occurring radium-226 (^{226}Ra) is the primary radionuclide of interest because phosphate ore contains this radioisotope, and phosphate mining activities can result in elevated levels of ^{226}Ra in surface soils. Areas with ^{226}Ra contributions will be identified on the basis of gamma emissions from ^{214}Bi. The final item in the above list represents radioisotopes present in the measuring equipment and all sources of "noise" in the final spectrum — including noise in the electronics.

A.3.2 Background Radiation

Levels of background radiation in the environment are variable and depend on many factors. Local geology has a large influence on the amount of background radiation because of the varying amounts of naturally occurring radioisotopes present in different rocks and soils. Because water is a good shielding material, the amount of water in the environment can also affect the amount of background radiation emissions from the ground surface. For example, a wetland area that has a few inches of standing water will have very low levels of surface radiation emissions.

The most prominent natural isotopes usually represented in aerial gamma-ray spectra are potassium-40 (^{40}K) (0.012% of natural potassium); two progeny products in the thorium-232 (^{232}Th) chain — thallium-208 (^{208}Tl) and actinium-228 (^{228}Ac); and two progeny in the ^{238}U chain — ^{214}Pb and ^{214}Bi. These naturally occurring isotopes typically contribute 1 to 15 μR/h to the background radiation field (Lindeken et al. 1972).

The contribution of radon and its progeny to the background radiation field depends on such factors as the concentration of uranium and thorium parent isotopes in the soil, the permeability of the soil, and the meteorological conditions at the time of measurement (Nazaroff 1992). Soil releases of radon lead to an average air concentration of 8 becquerels per cubic meter (Bq/m^3) (216 picocuries per cubic meter, pCi/m^3) over the northern hemisphere (NCRP 1991). Typically, the amount of airborne radiation from radon and its progeny contributes 1 to 10% of the natural background radiation level measured in aerial surveys conducted by DOE's Remote Sensing Laboratory.

The contribution of cosmic rays to the background radiation field varies with elevation above mean sea level and, to a lesser extent, with geomagnetic latitude and the 11-year solar sunspot cycle. In the continental United States, values range from 3.3 μR/h at sea level to 12 μR/h at an elevation of 9,800 ft (Klement et al. 1972). Calculations of the cosmic-ray contribution used in the data analysis discussed in this report depend solely on the variation with elevation.

Background radiation exposure rates have been measured at many locations across the United States. A National Council on Radiation Protection and Measurements report (NCRP 1987) gave results from seven different studies that measured exposure rates from background radiation. The smallest study included six measurements taken near Boston; the largest study involved 9,026 measurements in 102 different towns located in 24 states (most east of the Mississippi River). The exposure rates reported in these studies ranged from 7.9 to 26 μR/h (NCRP 1987).[2] These measurements include the exposure rate from cosmic radiation.

[2] Results were reported in mGy/yr and converted to μR/h, based on NCRP (1987) procedures (76μR/h = 1 mGy/yr).